At the Interface Between the Chemical and Power Industries

Victor M. Zavala

Assistant Computational Mathematician
Mathematics and Computer Science Division
Argonne National Laboratory

vzavala@mcs.anl.gov

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Outline

1. **Motivation**
   - Next-Generation Power Grid
   - Role of Chemical Industry

2. **Market Operations**
   - Market Structure and Pricing
   - Price Taking vs. Bidding

3. **Operational Opportunities**
   - Site-Wide Coordination and Material Inventories
   - Analogies with Building Energy Management

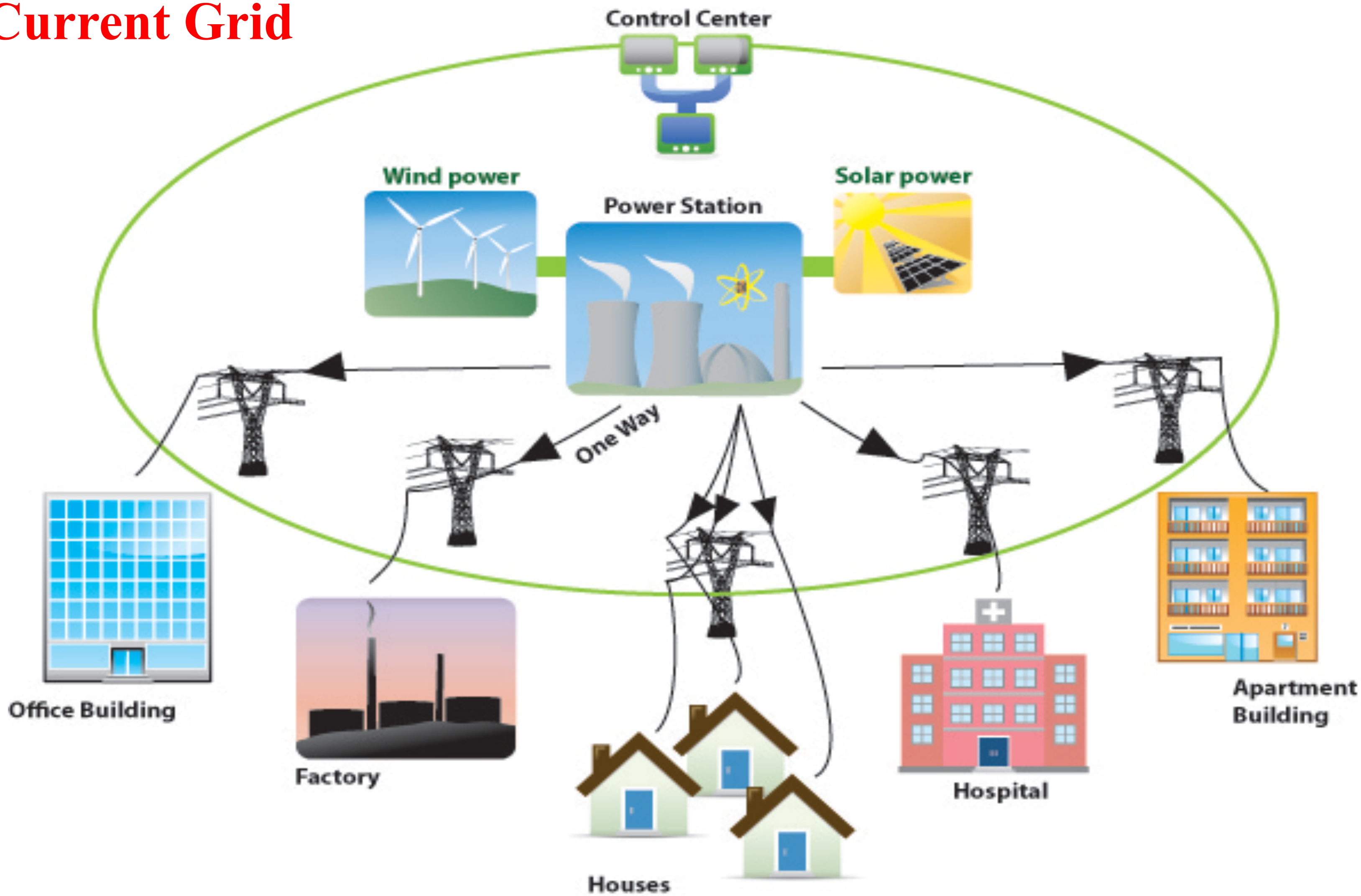
4. **Optimization Needs**
   - Capturing Dynamics in Planning

5. **Challenges and Discussion**

1. Motivation

Motivation

Current Grid



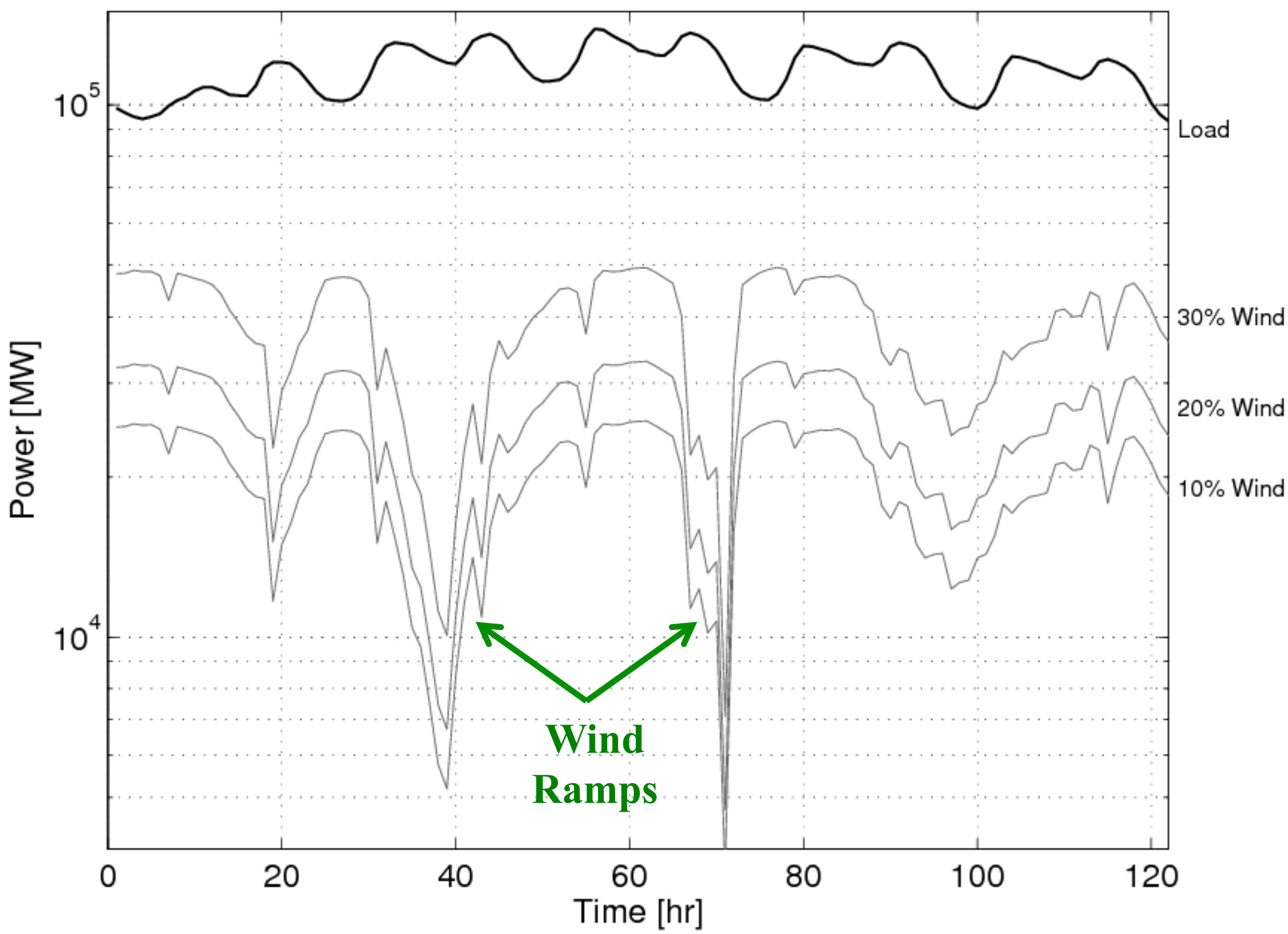
~ 70% Electricity from Central Coal Plants – CO_2 Emissions

Limited Market Control – Demands are Inelastic, Limited Electricity Storage

Cannot Sustain High Renewable Supply and Contigencies

Motivation

Future: Supply (Wind) and Elastic Demands Vary at <u>Higher Frequencies</u>

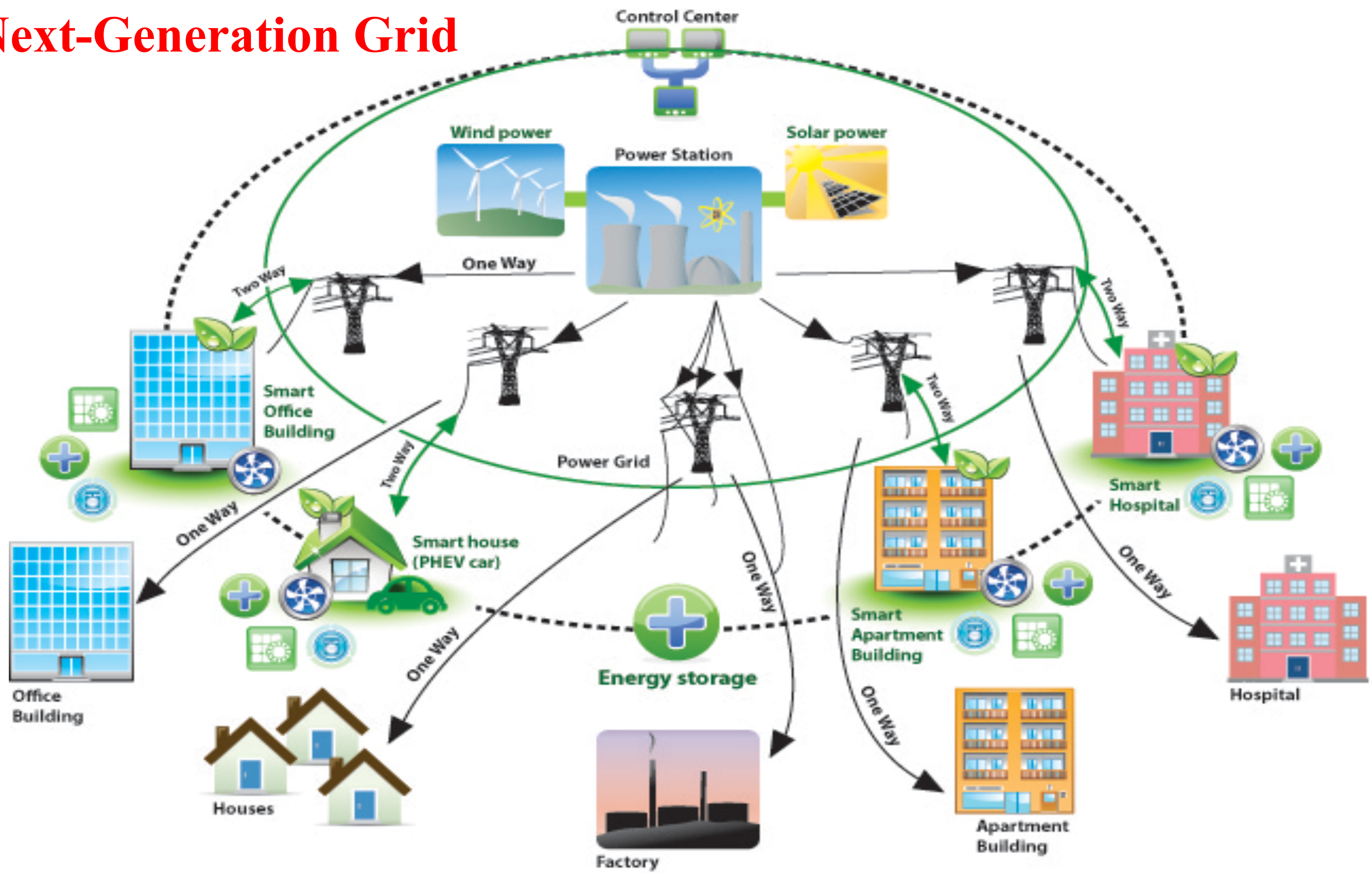


<u>Anticipating</u> Weather and Loads is Critical -Avoid <u>Ramping</u> Constraints-

Lack of Anticipation = Market Volatility (Price Spikes), Vulnerability

Motivation

Next-Generation Grid

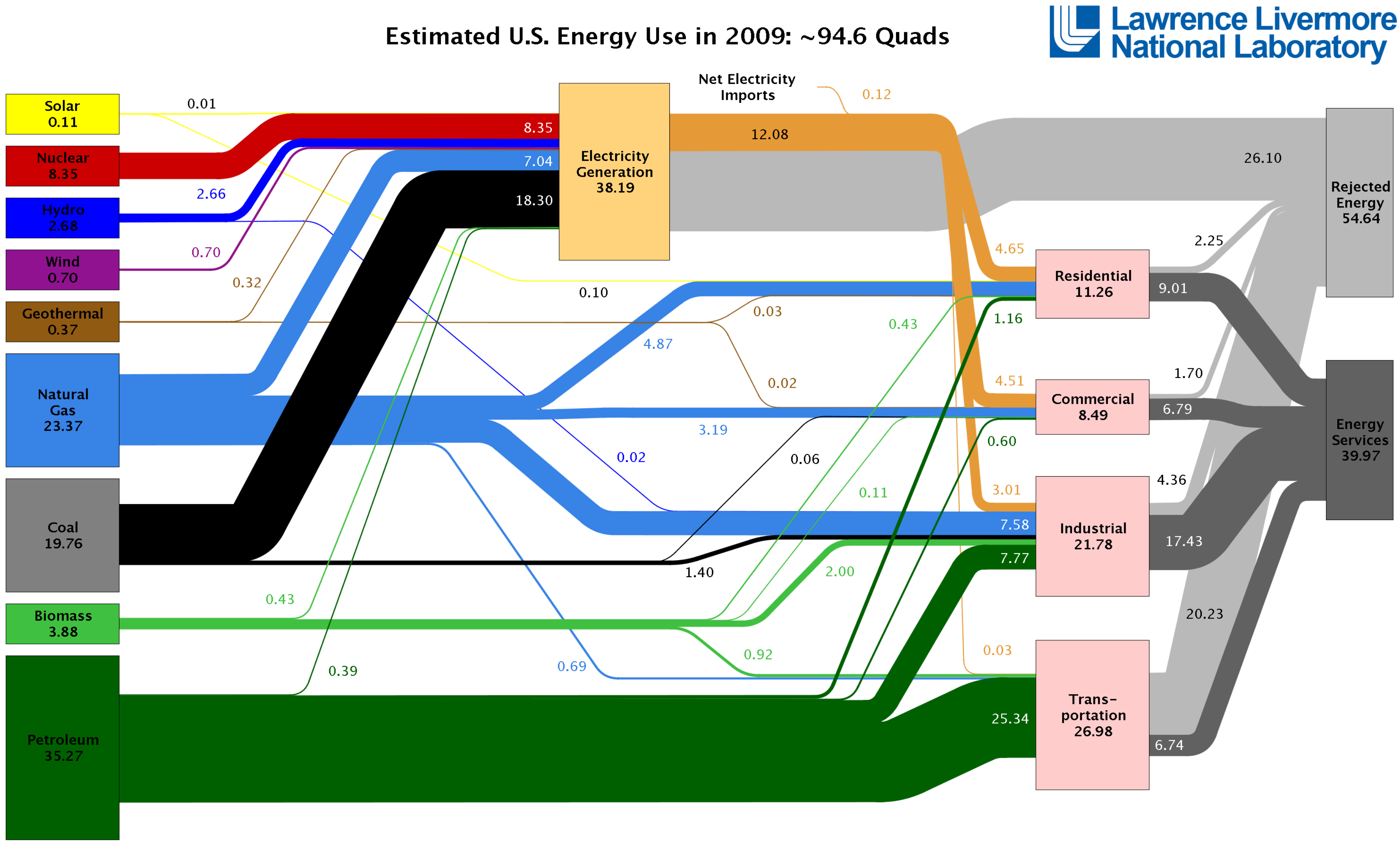


Major Adoption of <u>Renewables</u> -30%-

Prices + Storage Critical (PHEVs, Compressed Air, Batteries) = <u>Fast Ramping</u>

Key Observation of This Talk: Chemical Industry Can Exploit <u>Material</u> Inventories

Motivation



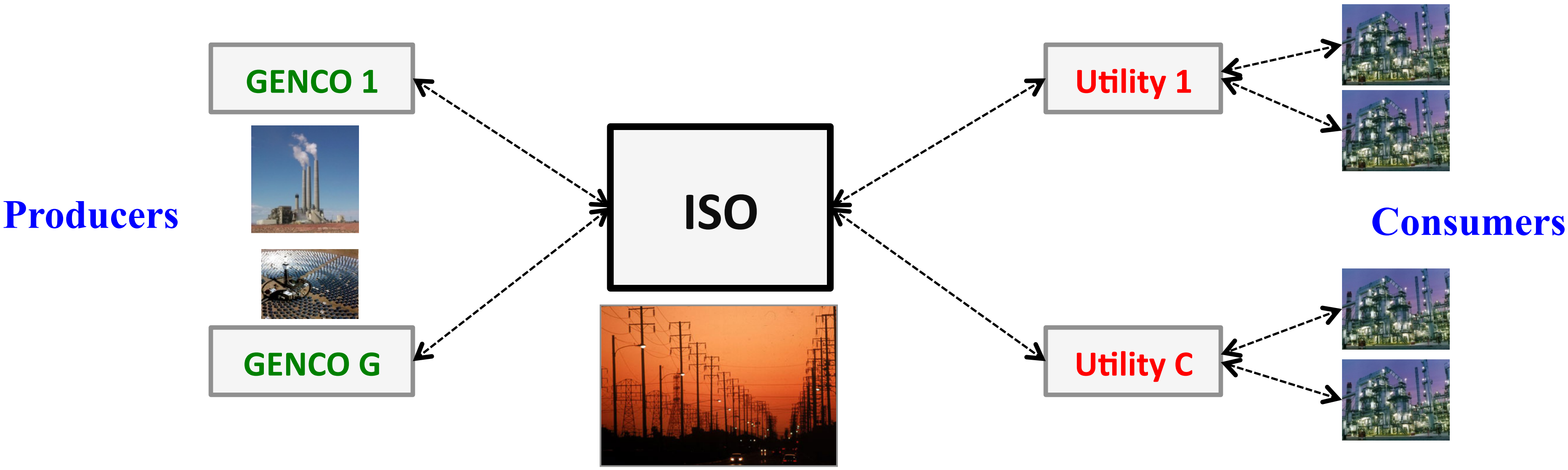
Source: LLNL 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Industry Accounts for 20-25% of U.S. Electricity Demand, 30% of Natural Gas

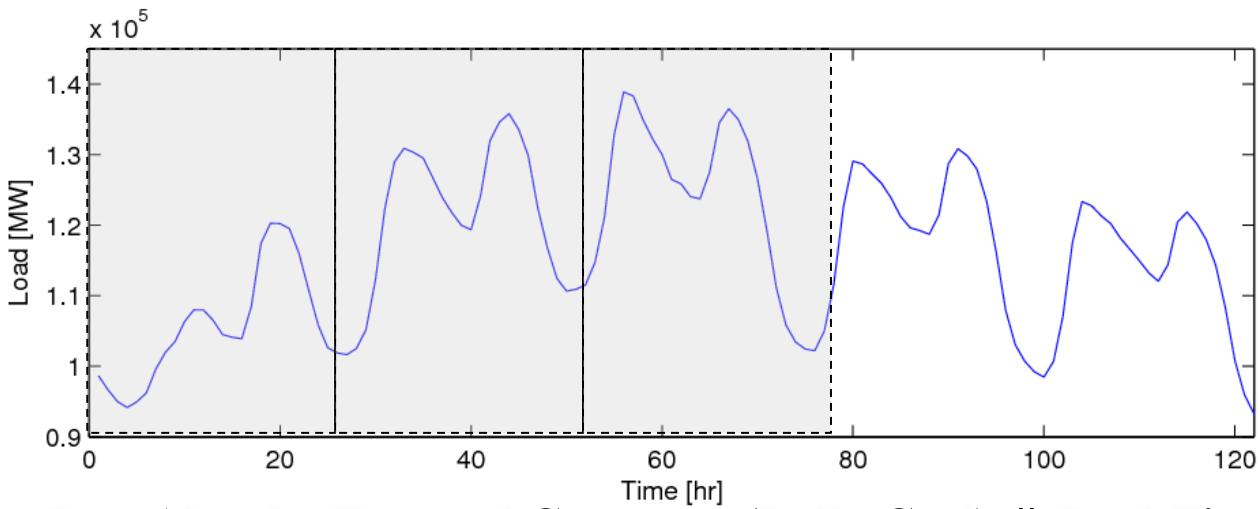
Electricity = Pumping, Refrigeration, Lighting, Natural Gas = Steam, Reforming

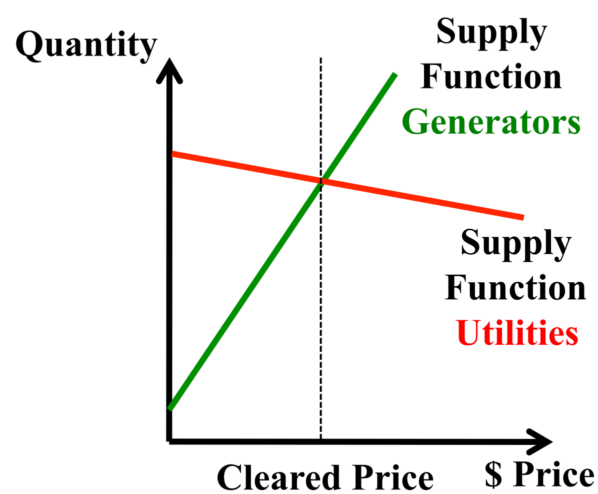
2. Market Operations

Market Operations



- GENCOs and Utilities <u>Bid</u> in Day-Ahead and Real-Time Markets
- ISO Clears Markets To <u>Maximize Social Welfare</u>





Day-Ahead = Forward Contracts (Bulk, Coal) || Real-Time = Corrections (Ramp, Gas)

Poor Forecast of Renewables and Loads = Real-Time Price Volatility

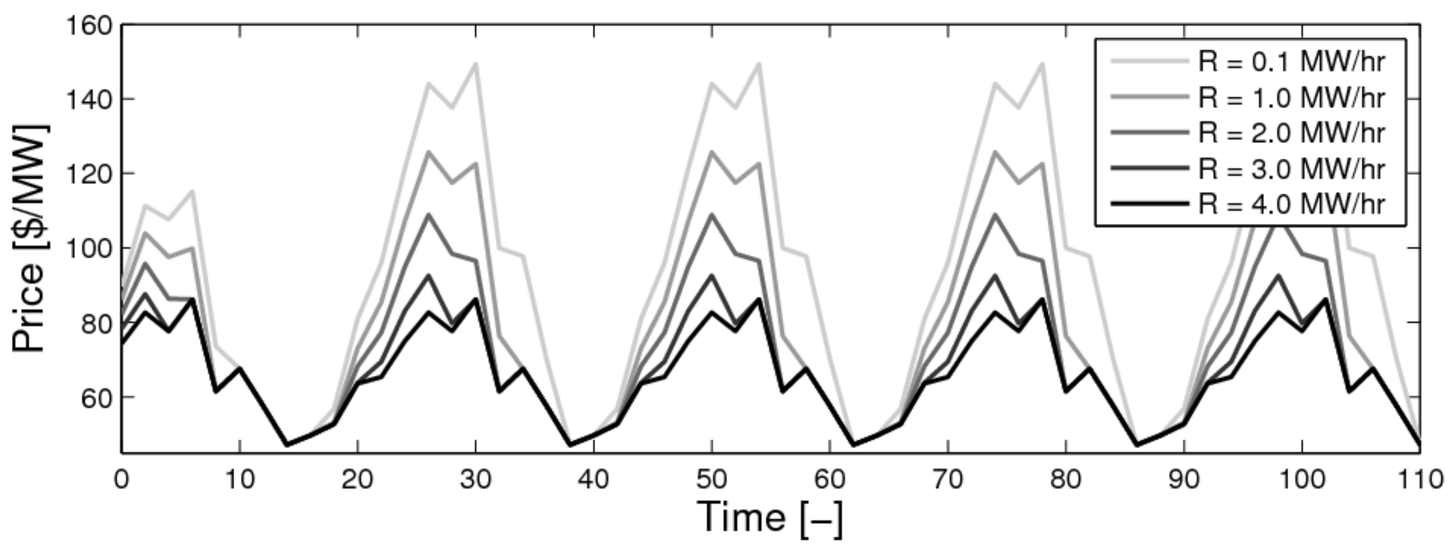
Dynamic Electricity Markets

Supply Function-Based Dynamic Game Models *Kannan & Zavala., 2010*

- Effect of Physical Constraints on Market Stability

$$\max_{a_i^t,b_i^t,q_i^t} \sum_{t=1}^{T}\left(\overbrace{\left(\frac{q_i^t+a_i^t}{b_i^t}\right)}^{\textbf{Price}} q_i(t) - C_i(q_i(t))\right)$$

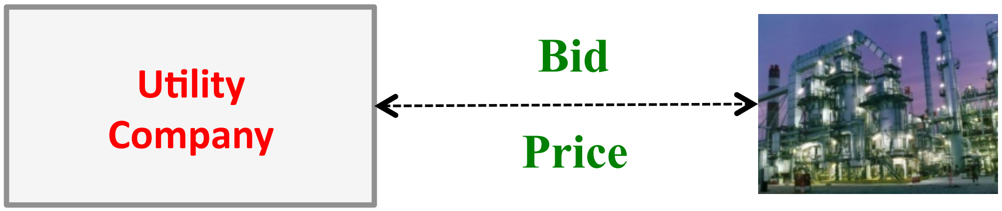
$$\left.\begin{array}{l} \left\{ \begin{array}{ll} & q_i^t \le cap_i^t \\ & q_i^{t+1} - q_i^t \le R_i^t \\ s.t. & \frac{q_i^t+a_i^t}{b_i^t} = \frac{c^t+\sum_{i=1}^{N} a_i^t}{d^t+\sum_{i=1}^{N} b_i^t} \\ & q_i^t \ge 0 \end{array} \right\}, \underbrace{\forall t = 1,2,..,T}_{\textbf{Horizon}} \end{array}\right\} \underbrace{\forall i = 1,...,P}_{\textbf{Generators}}$$

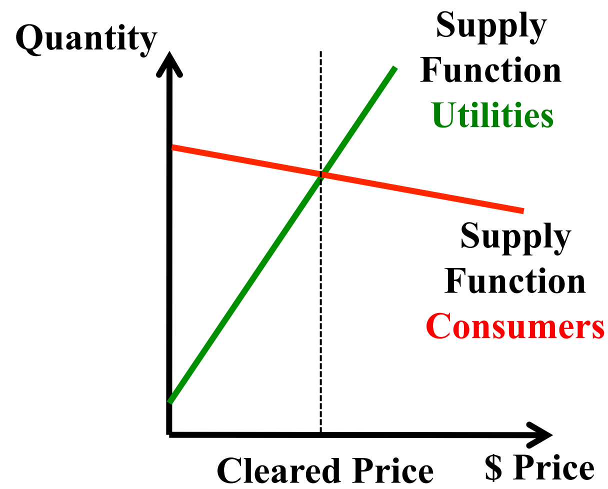


Ramping Constraints Make Prices Volatile || Ramping Capacity is an Asset in Smart-grid

Market Operations

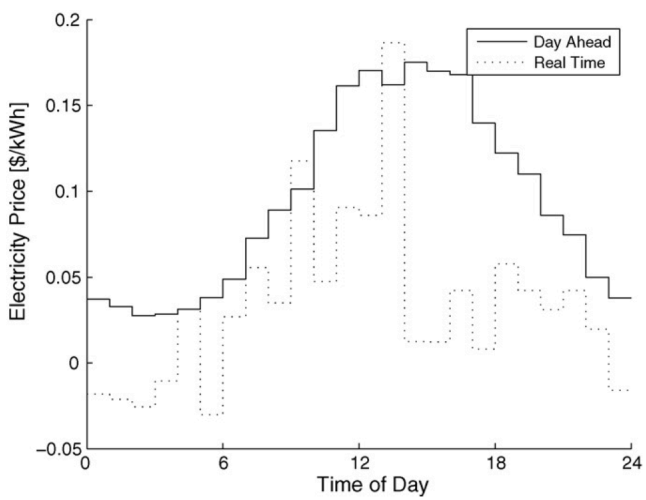
Chemical Industry: From Price-Taker to Bidder



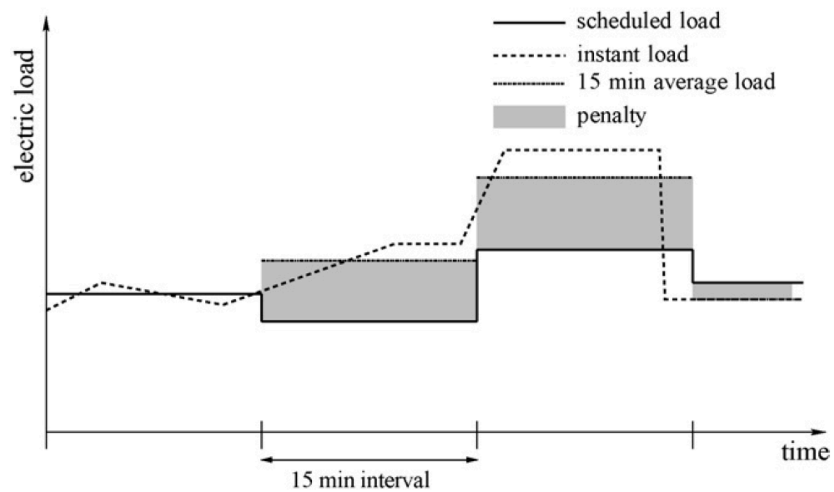


Price taking: Day-Ahead, Real-Time, Demand-Charge (High Uncertainty)

Bidding: Plan Day-Ahead Demands & Track Profile (Less Uncertainty for Utility & Site)



Baumrucker & Biegler, 2010 (Piping)



Noble & Morari, 2010 (Steel Plant)

Chemical Sites are Large Consumers → Can Exert Market Power on Utilities

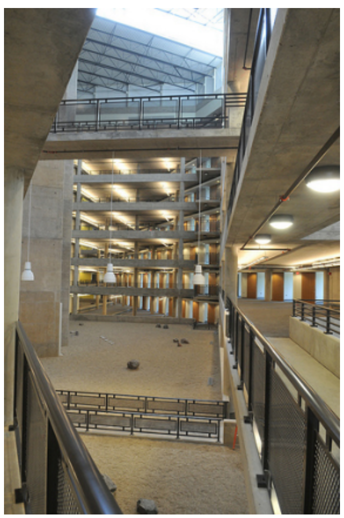
Incentives Increasing with Demand-Response Programs

2. Operational Opportunities

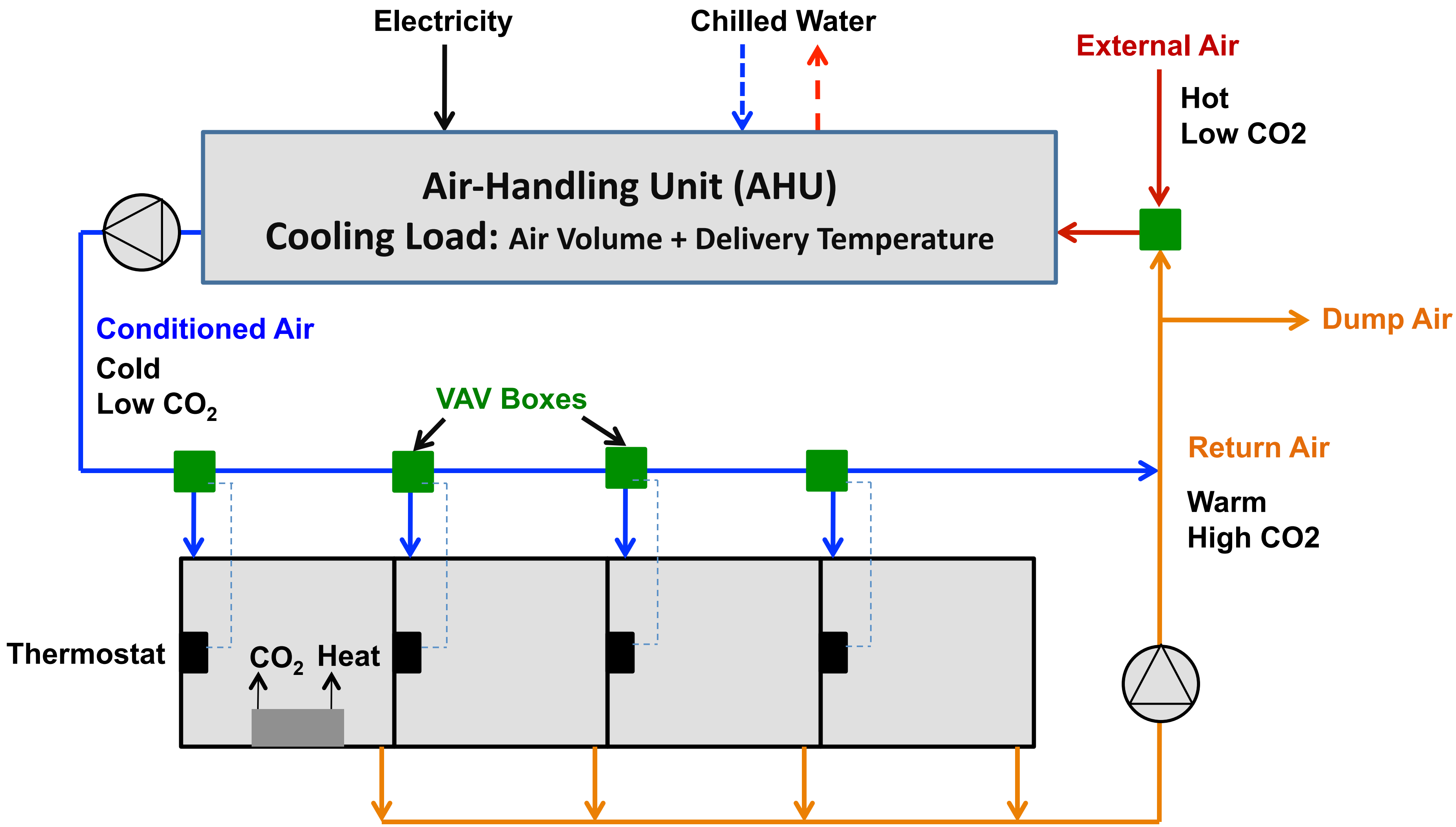
Building Energy Management

Collaborative Project: Argonne-Building IQ
"Proactive Energy Management for Building Systems"

Mike Zimmermann, Tom Celinski, Peter Dickinson (BIQ), and Victor M. Zavala (ANL)



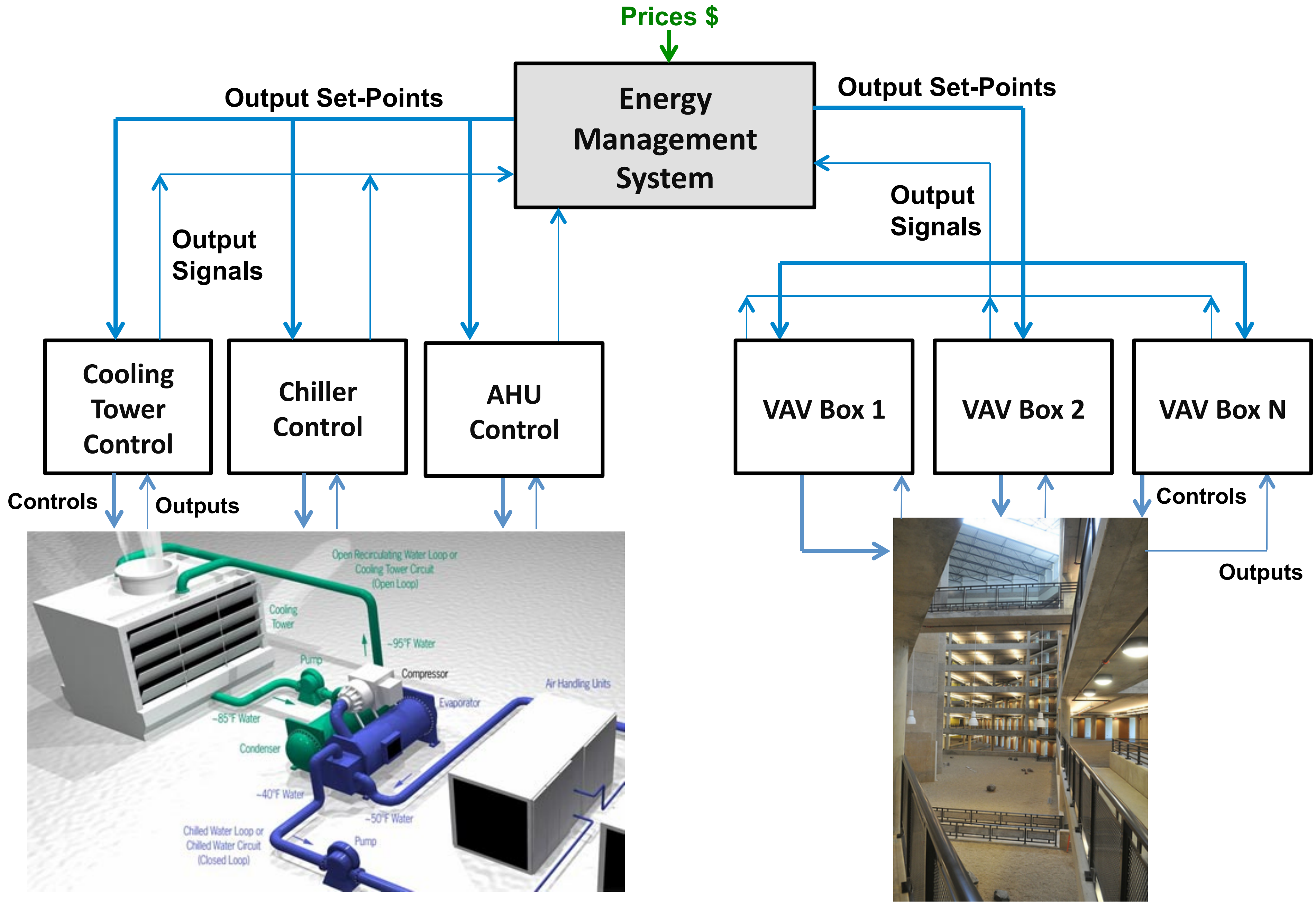
Building Layout -Cooling Mode-



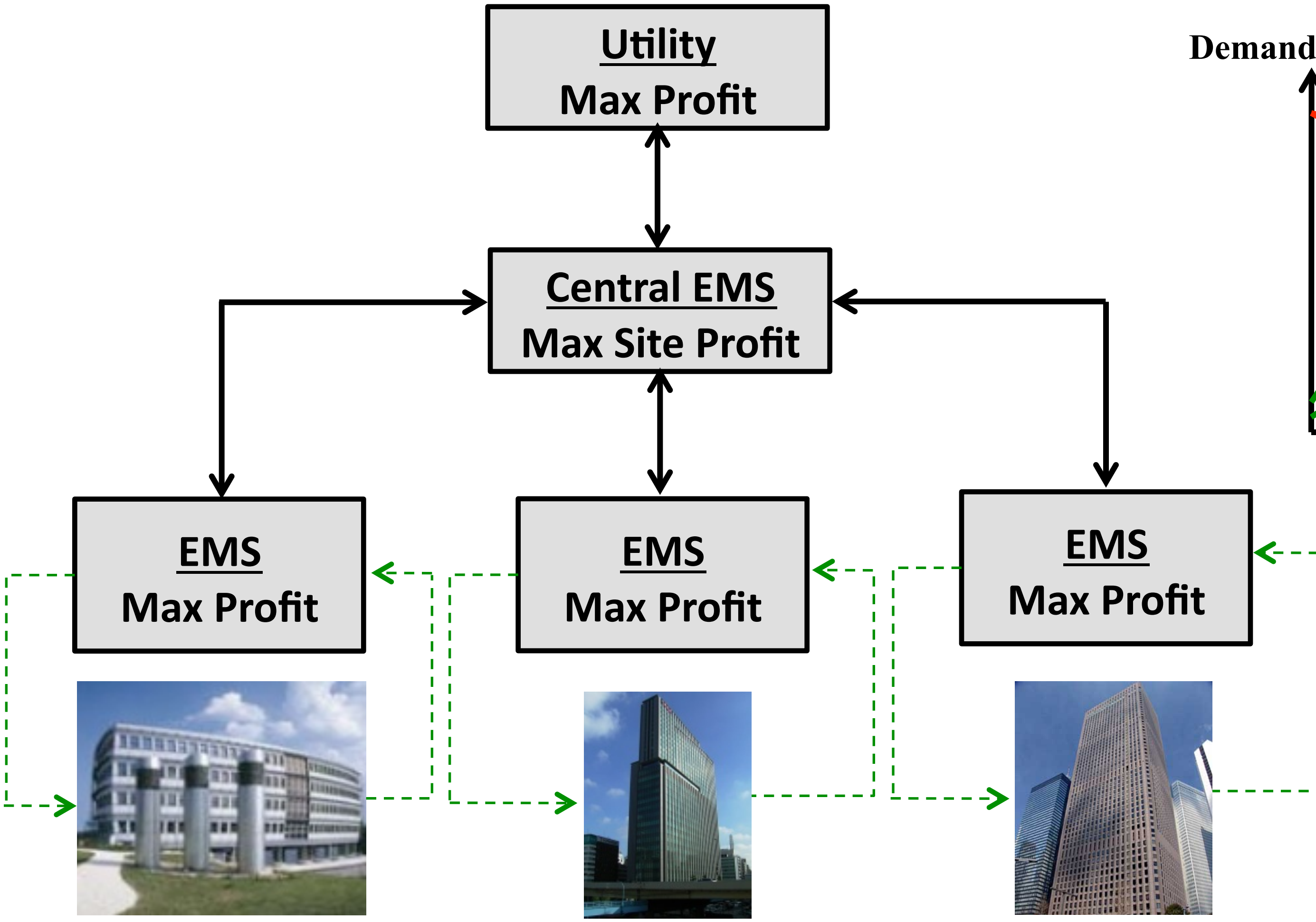
Sources of Unnecessary Demands:

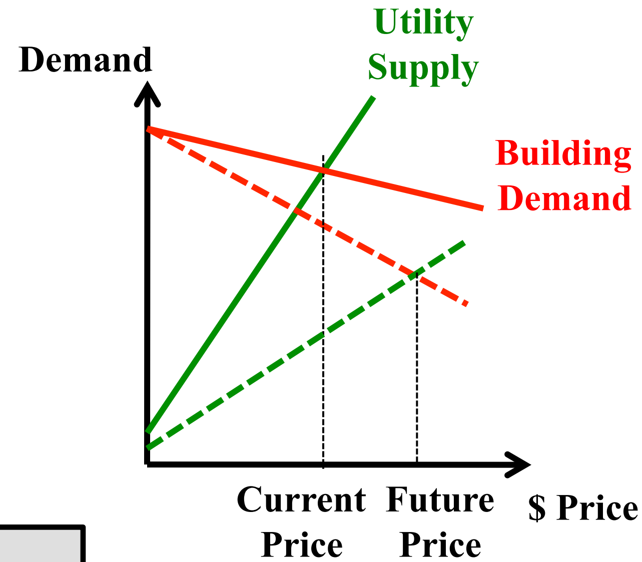
- Sensor Placement -Temperature, Humidity, CO_2- (Perceived vs. Actual Temperature)
- Unnecessary External Air Conditioning (Reuse Return Air as Much as Possible)
- Equipment Operated at Low Efficiencies (Fans, VAV Boxes, Boilers, Chillers)

Building Automation System



Building Energy Management



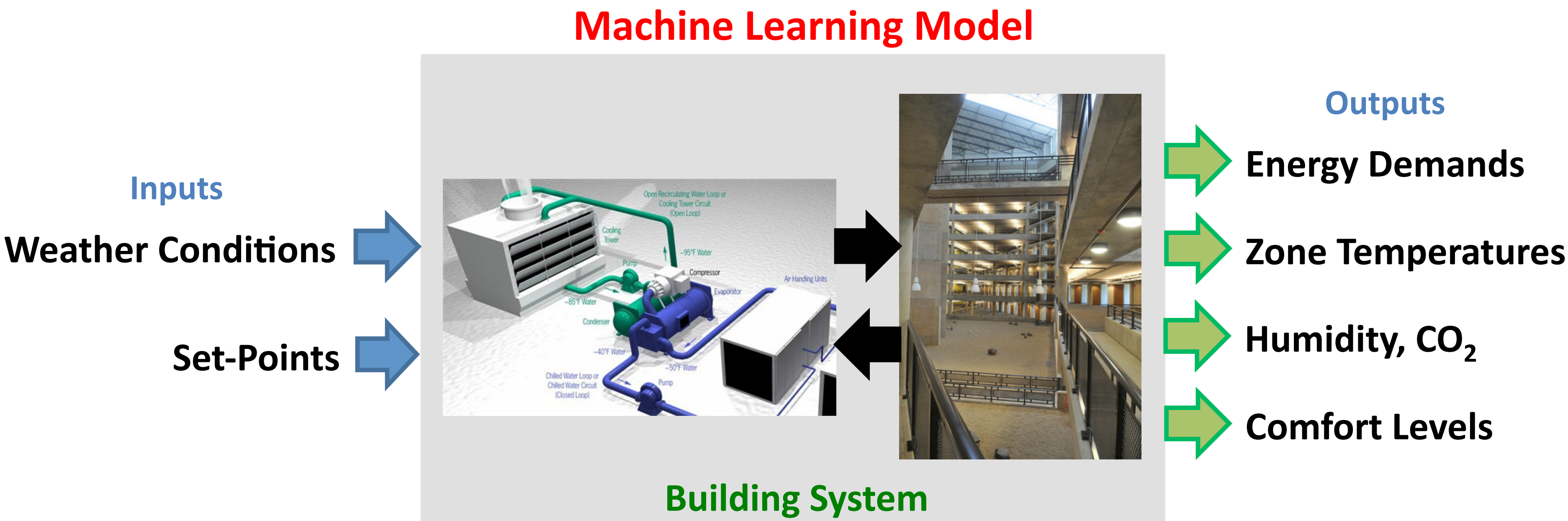


Coordinate Demands and Quantify Shedding Potential in Real-Time (Demand-Response)

Coordination Enables Running Central Boiler and Chillers at High Efficiency

Shedding Potential Limited (Limited Storage) = Sacrifice Comfort, Exploit Occupancy

Building Energy Management



- **Real-Time Planning Problem with Machine Learning Model**
  Solved Every 10 Minutes, Foresight of 2-24 Hours
  Quantify Electricity Demand as Function of Building Conditions
  Building Model Re-Trained Daily

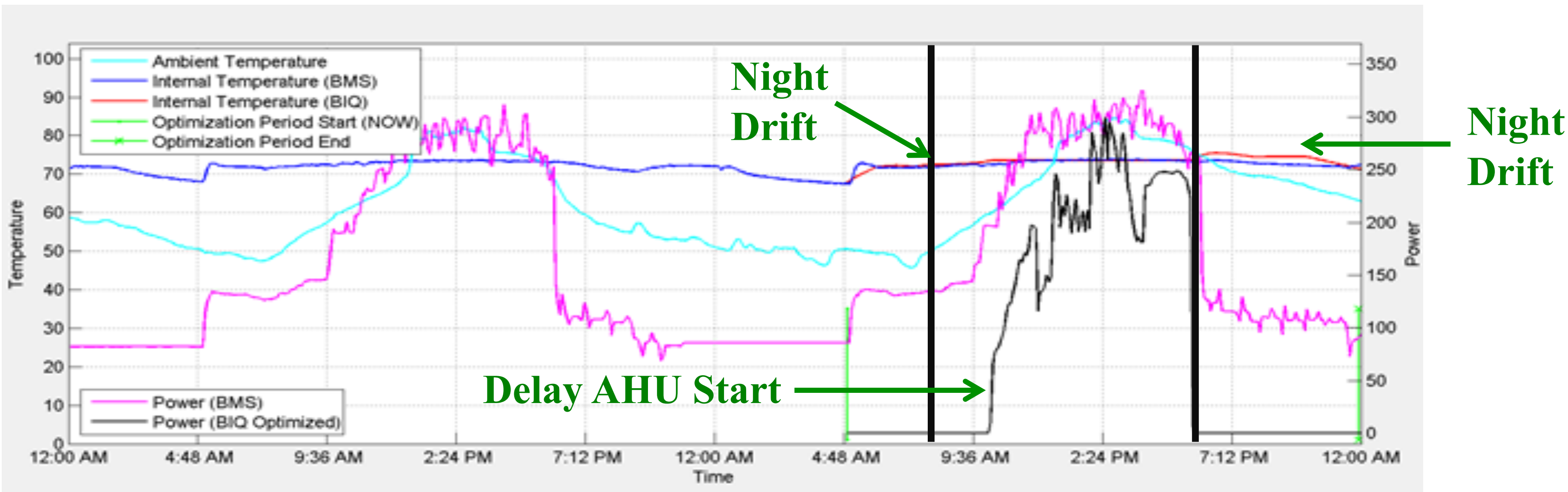
- **Trade-Off:** **Comfort vs. Energy Demands vs. CO_2 emissions**

- **Exploit Sensor Information:** **Occupant Tracking, Disaggregate Demands**
  Capture Spatio-Temporal Variations

Argonne's TCS Building Implementation

Testing in Large Commercial Building at Argonne:

- 700 Occupants, Floor Space 200,000 sq. ft, 7 Air-Handling Units, Computing



<u>Energy</u> (CO_2) Savings of 20-45% from AHUs Demands

Key: <u>Relax</u> Comfort in Unoccupied Spaces, Exploit Weather Forecast to Delay AHU Start

Building Energy Management

Occupant Tracking, TCS Building at Argonne *Skow, Domagala, Cattlet. 2010*

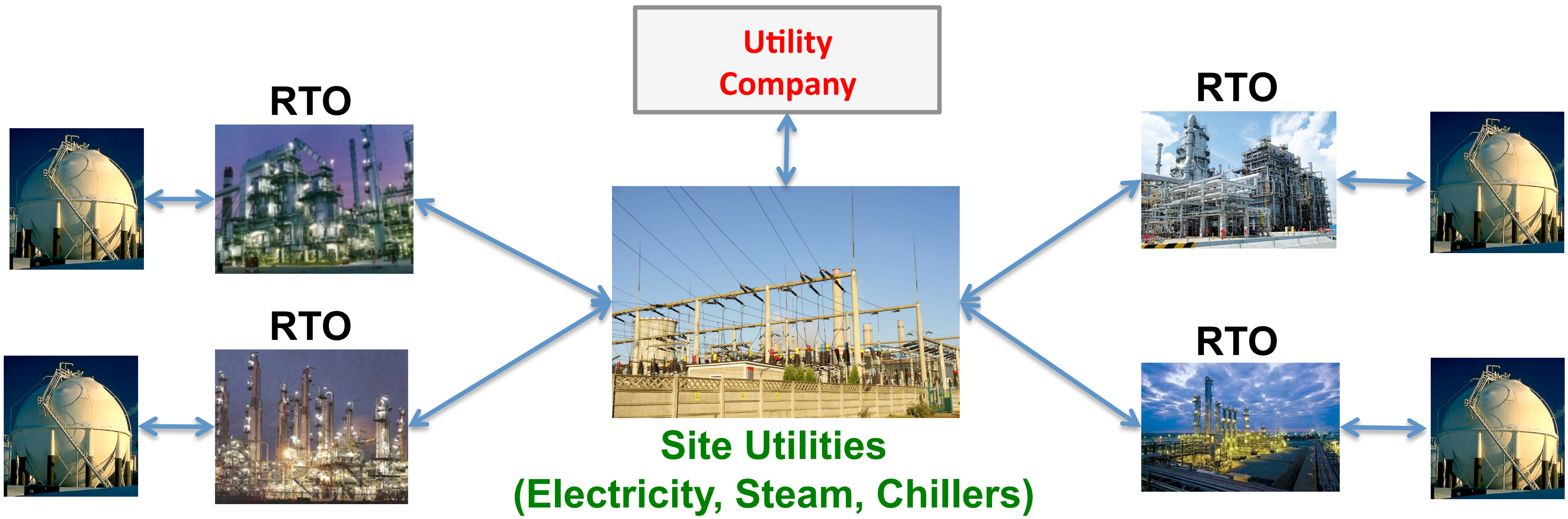
Operational Opportunities Chemical Industry

Inventories Provide a Unique Opportunity to Exert Market Power – Fast Load Shedding

- Mechanism to Mitigate Inventory Costs = Inventory as an Asset

Need Coordination of RTOs & Site-Wide Planning = Who Manages Energy? (Conflicting)

- Status of Site-Wide RTO, RTO for Utilities?



Need to Assess Loads as Functions of Production Levels and Weather

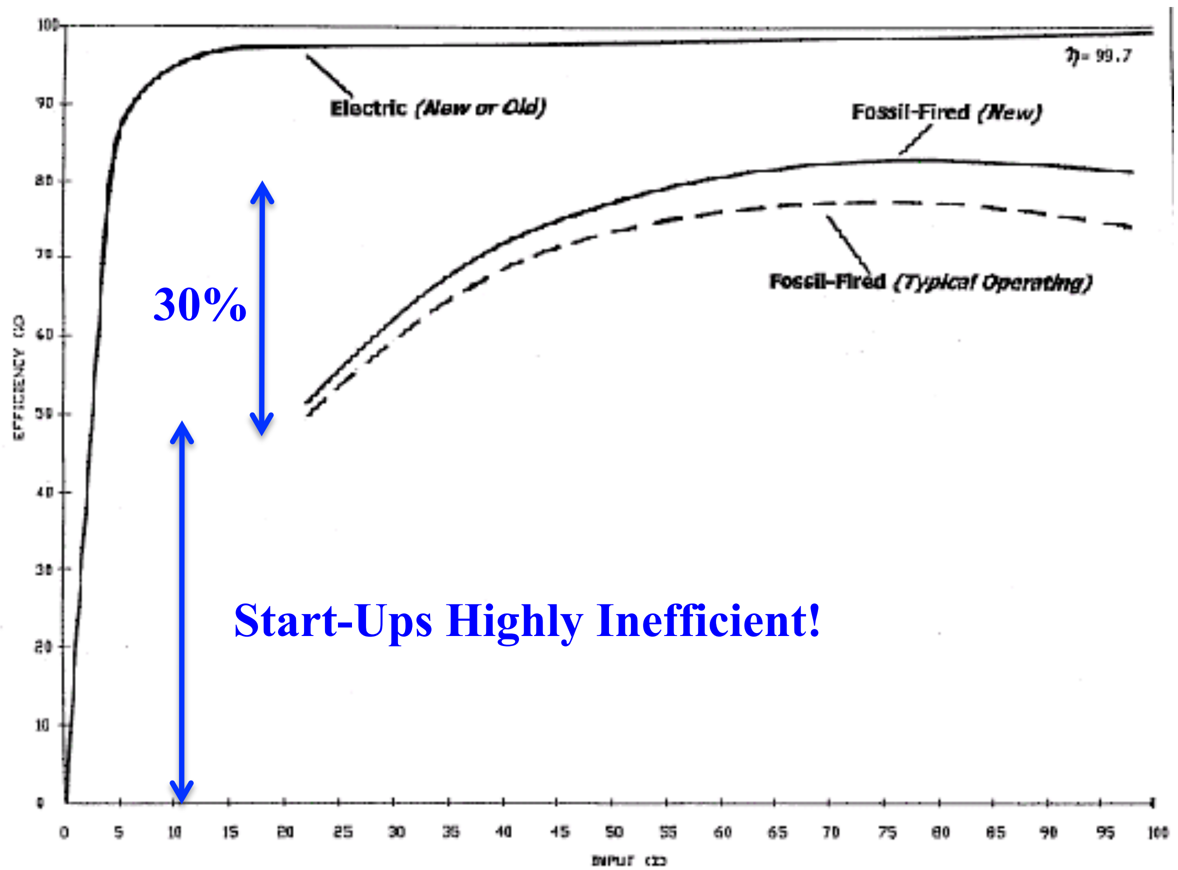
Need to Manage Risk in Day-Ahead and Real-Time Bidding

Disaggregate Electricity Metering (Plant by Plant) → Discover Demand Behavior

Operational Opportunities Chemical Industry

Coordinate RTOs to Operate Boilers and Chillers at High Efficiencies

- **Saves Energy (Not Only Cost) and Emissions**
- **Shift Local RTOs Objectives to Central Efficiency Objective**



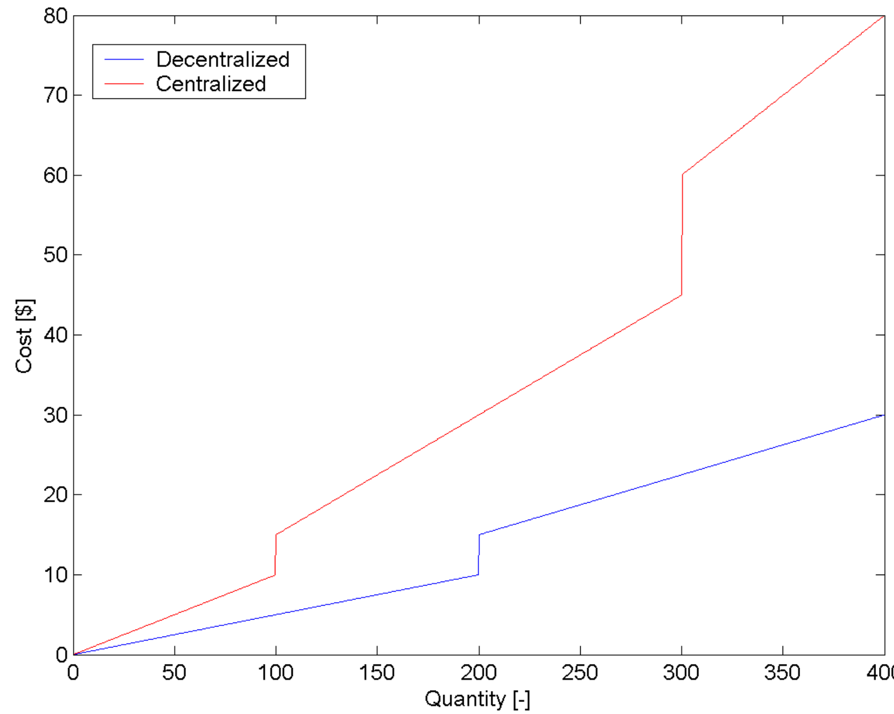
Billing Structures and Co-Generation

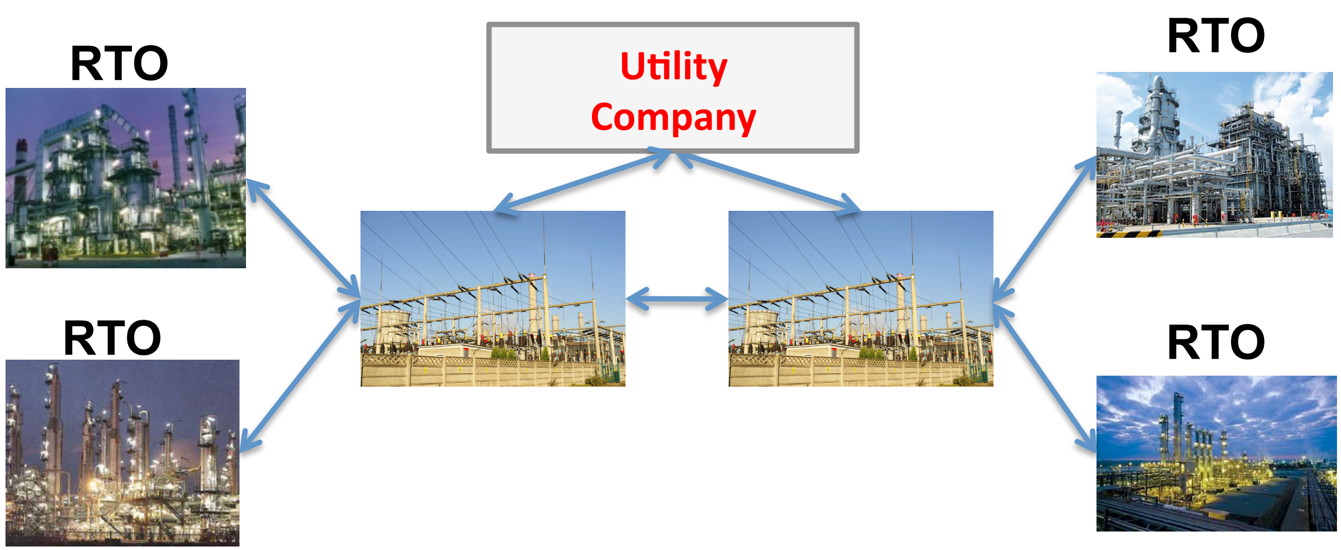
Opportunities for Retrofitting Generation

- Bid in Real-Time Market, Fuel Cells

Decentralize Demand Charges

- Function of Quantity (Nonlinear Cost)
- Decentralized Utilities





5. Challenges and Discussion

Challenges

Motivation:

- Smart-Grid: Emphasis on Ramping (Ancillary Services) and Demand Elasticity
- Chemical Sites Valuable Participants (Large and Flexible Demands, Exploit Inventories)
- Central Coordination of RTO and Production Planning

Models and Algorithms

- Capture Short Time-Scales in Planning (Day-Ahead)
- Utilities RTO, Bidding Formulations, Risk Management
- Need US-Scale Study on Impact of Industrial Sites and Role in Smart Grid
- Utilities Re-Evaluation of Industrial Billing Structures & Contract Design

Discussion:

- Current Status of Billing Structures
- Current Energy Management Practices
- Federal Mandates

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